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Perception and Action in Golf Putting: Skill Differences Reflect Calibration

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We assessed how golfers cope with the commonly observed systematic overshoot errors in the perception of the direction between the ball and the hole. Experiments 1 and 2, in which participants were required to rotate a pointer such that it pointed to the center of the hole, showed that errors in perceived direction (in degrees of deviation from the perfect aiming line) are destroyed when the head is constrained to move within a plane perpendicular to the green. Experiment 3 compared the errors in perceived direction and putting errors of novice and skilled players. Unlike the perceived direction, putting accuracy (in degrees of deviation from the perfect aiming line) was not affected by head position. Novices did show a rightward putting error, while skilled players did not. We argue that the skill-related differences in putting accuracy reflect a process of recalibration. Implications for aiming in golf are discussed.

Keywords: golf putting, expertise, information, perceptual error, far aiming

The golf instructional literature conventionally ascribes great significance to movement technique, yet also increasingly emphasizes perception as key to success in golf putting (e.g., Farnsworth, 1997; Mangum, 2008; Pelz, 2000). Pelz (2000), for instance, elaborately discusses the importance of visual perception in relation to green reading and for determining the direction of the putt. Likewise, also there is an increasing awareness in sport science that successful putting entails more than proficient movement control, but requires, apart from many other factors, skillful perception. Thus, Karlsen, Smith, and Nilsson (2008) have recently argued that

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stroke execution has a relatively minor influence on direction consistency in golf putting among elite players. Moreover, there is now compelling empirical evidence for skill-related differences in visual search strategies for a range of precision-aiming tasks in ice hockey (Panchuk & Vickers, 2006), the soccer penalty kick (Wilson, Wood, & Vine, 2009), and basketball free throw (Wilson, Vine, & Wood, 2009), as well as in golf putting (van Lier, van der Kamp, & Savelsbergh, 2010; Vickers, 1992, 1993) (for an overview, see Mann, Williams, Ward, & Janelle, 2007).

Despite this growing awareness of the importance of skilled visual perception, sport scientists and pundits alike have typically neglected that perception is not always veridical; it is easily fooled by visual illusions. A handball goalkeeper, for instance, can create a size illusion by assuming postures that mimic Müller-Lyer configurations. Van der Kamp and Masters (2008) demonstrated that these illusionary postures affected the direction of penalty free throw without the penalty taker being mindful of this influence. To further the understanding of how nonveridical perception affects sports performance, the current study scrutinizes the impact of errors in the perception of direction of the aiming line in golf putting. That is, when addressing the putt most golfers look back and forth between the ball and the hole, standing parallel to the left (for a right-handed player) of the line between the ball and the hole before they actually perform a swing. Intriguingly, Johnston, Benton, and Nishida (2003) observed that golfers, whether skilled or not (i.e., handicaps ranging between 0 and 30), make systematic overshoot errors in the perception of the direction of the aiming line between the ball and the hole. That is, the participants in the study of Johnston et al. (2003) had to align a pointer in the direction of the hole. Standing to the left of the pointer resulted in clockwise alignment errors, while standing to the right resulted in counter-clockwise alignment errors.¹

This effect is consistent with observations of Koenderink and colleagues (Cuijpers, Kappers, & Koenderink, 2000, 2003; Koenderink & van Doorn, 1998; Koenderink, van Doorn, & Lappin, 2000, 2003) for direction judgments in the near field (i.e., distances smaller than 10 m.). They report that people make consistent and systematic perceptual errors when judging the direction of a pointer relative to a target object when the point of observation is not aligned with the pointer and the target (i.e., exocentric pointing). It is not particularly clear why a physically straight line between the two objects is not perceived as straight. Nevertheless, it can be shown geometrically that the perceived direction depends on the ratio of the distances of the pointer and the target to the observer (see Koenderink et al., 2003). One hypothesis is that the perceptual errors are associated with the detection of information that relates to the distance of the pointer, which may to some extent be indistinct due to the pointer's rotation in depth relative to the observer's line of sight (i.e., toward and away). This is consistent with the finding that, under binocular viewing, the variability in perceived directional error is reduced as compared with monocular viewing, possibly because it enhances the pickup of information that specifies the pointer's rotation in depth (Cuijpers et al., 2000). The conclusion is that when the rotation of the pointer occurs in a plane perpendicular to the observer's line of sight (i.e., no motion in depth relative to the observer), this perceptual error will vanish (compare left and middle panel of Figure 1).

Except for golfers making systematic overshoot errors in the perception of the direction of the aiming line between the ball and the hole, Johnston et al. (2003) reported two more remarkable findings. First, the perceptual errors made in the

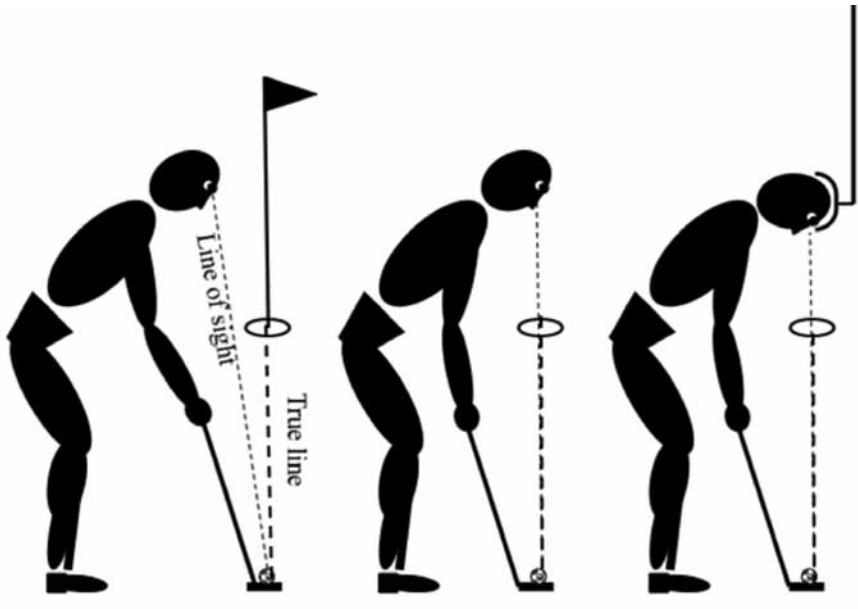


Figure 1 — Schematic representation of the line of sight in relation to the ground plane and the true line between the ball (or pointer) and the hole as a function of head position. With the eyes above the hand, that is, inside the true line, the angle between the line of sight, the ground surface, and the true line between the ball and hole (i.e., perfect aiming line) is nonperpendicular (left panel); with the eyes straight above the ball (middle and right panels), the angle is perpendicular. The right panel shows the head position in Experiment 2 and 3 in which the head was restricted such that the head was constrained to move in the plane perpendicular to the ground surface.

pointing task did not translate into putts missed from the practiced side, as the error in the pointer alignment did not correlate with the putting error. Yet, for the unpracticed side a correlation became apparent between putting variability and the errors in perceived direction error. It seems that practice or skill in some way make the putting actions refractory to perceptual distortions. Johnston et al. (2003) did not address this issue in detail. Therefore, the aim of the current series of experiments is to ascertain how skilled golfers have managed to overcome the systematic perceptual distortions when performing putting actions.

The relation between perception and action is a key issue in Gibson's (1986) ecological approach. Proponents of the ecological approach hold that for any action a lawful relation exists between optical information² and movement (Warren, 1988; see also van der Kamp, Oudejans, & Savelsbergh, 2003). In its simplest appearance, this so-called law of control can be formally expressed as

$$M(t) = a + b \times I(t)$$

in which $M(t)$ stands for a particular movement variable (e.g., the orientation of the club head at impact), $I(t)$ stands for a particular optical information variable (e.g., specifying the direction toward the hole), and a and b stand for constants that reflect the precise relationship between the movement and information variables.

Two processes of change are discerned that enhance the adaptability of the law of control (e.g., Jacobs & Michaels, 2007; Withagen & Michaels, 2005). First, the education of attention comprises a change of the optical information variable that enters a particular control law. During learning, the more useful or specifying variables come to be exploited (Savelsbergh & van der Kamp, 2000). Secondly, calibration refers to a change in the relation between the movement and optic variables by tuning of the constants a and b . Hence, the skill-related differences such as observed in the golfers by Johnston et al. (2003) may reflect the use of different optical variables in guiding the putting actions, or alternatively, a difference in how the relation between the movement and optic variables is tuned or calibrated.

In this respect, it is pertinent that golfers are insistently told to position their eyes straight above the ball while addressing it for putting, while gaze is at the ball until impact (e.g., Farnsworth, 1997; Pelz, 2000). Novice players tend to position their eyes roughly above their hands on their own accord. In golf this is referred to as inside the target line (see Figure 1, left panel). Consequently, the point of observation relative to the aiming line between the ball and the hole is likely to be different dependent on skill level. With the eyes above the hands, the player's line of sight is *not* perpendicular to the plane (i.e., ground surface) through the true line between the ball and the hole (i.e., perfect aiming line), increasing the likelihood of errors in perceived direction. Possibly, these errors are minimized when placing the eyes straight above the ball, as this head position results in the line of sight being perpendicular to the ground surface (see Figure 1).³ In other words, dependent on the angle between the line of sight, the ground surface and the true line between the ball and hole, more reliable optical information may become available that specifies the direction of the line between the ball and the hole and the required orientation of the club head during the swing. This is not unlike perceptual errors among assistant referees in soccer who, dependent on their position relative to the attacking and defending players, can or cannot access information that specifies off-side (Oudejans, Verheijen, Bakker, Gerrits, Steinbruckner, & Beek, 2000; but see Catteeuw, Helsen, Gilis, Van Roie, & Wagemans, 2009). Skilled golfers therefore may have to overcome the (initial) errors in perceived direction by learning to position the head and eyes directly above the ball enabling them to detect and use specifying information, a change which is reminiscent of education of attention. Johnston et al. (2003) did not report the head position, but it is not unlikely that the players did not maintain the head directly above the ball during the perceptual task (i.e., orienting the pointer in the direction of the hole). Obviously, the untested proposition that errors in perceived direction are a function of head position (or more precisely, the line of sight) relative to the ball (and ground surface) makes or breaks these conjectures. Therefore, Experiments 1 and 2 evaluated, by varying head position relative to the ball, whether the perceived direction of the aiming line between the ball and the hole is biased as well as whether this bias is mediated by head position.

A second explanation, which also calls upon the education of attention to distinguish novice and skilled putting performance, is granted by the two-visual systems model proposed by Milner and Goodale (1995, 2008; for ecological conceptualizations of this model, see Michaels, 2000; van der Kamp et al., 2003; van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008). The two-visual systems model distinguishes between the detection and use of optical information for perception and the detection and use of information for action (i.e., movement control). These

two functions engage separate cortical areas of the brain (i.e., the posterior parietal cortex for action, and the inferior temporal cortex for perception), and much more pertinent to the present concerns, they exploit different sources of optical information. The automated, unconscious guidance of actions primarily relies on egocentric information (i.e., specifying objects and places dependent of viewpoint in absolute metrics). However, conscious perception first and for most involves the use of allocentric information (i.e., specifying objects and places independent of viewpoint and in relative metrics). It is for this reason that perception is much more susceptible to optical illusions than action (e.g., Bruno, Bernardis, & Gentilucci, 2008). Yet, it has been argued that only with an increased efficiency and automatization of action during learning, actors come to fully rely on egocentric information. By contrast, the initial conscious guidance of action that characterizes novice performance is thought to be much more subject to allocentric information (Willingham, 1998; van der Kamp et al., 2003). Gonzalez, Ganel, Whitwell, Morrissey, and Goodale (2008), for example, found that unfamiliar awkward grips were much more susceptible to a size-contrast illusion than the precision grips that participants habitually used to grasp small objects, suggesting a change in the contribution of illusion inducing allocentric information. In other words, skilled golfers may exploit different sources of optical information for making conscious perceptual judgments on the direction of the (virtual) line between the ball and hole than in the control of club head orientation during the putting action, irrespective of the position of the head (and the eyes). Yet, putting from the unpracticed side may induce conscious engagement of the perception system, increasing the likelihood of perceptual error (see Johnston et al., 2003; van der Kamp et al., 2008). Again, the assumption here is that with increases in skill, golfers allocate attention to different optical variables to guide their putting actions. The aim of Experiment 3 was to test this hypothesis.

Finally, the errors in perceived direction may evaporate from the putting action because the skilled golfers have learned to correct for the perceptual distortion (Johnston et al., 2003). This would point to a process of calibration, in which the relationship between the movement and optic variables is adjusted based upon error feedback from prior actions (Bedford, 1999; Withagen & Michaels, 2005). This account differs from the former two in that calibration does not presume a change in the variable that is used, which characterizes education of attention. Rather, it suggests that the initial overshoot is overcome by aiming the ball slightly to the opposite side of the hole. Nonetheless, Withagen and Michaels (2005; see also Rieser, Pick, Ashmead, & Garing, 1995) found that calibration is functional, and not effector specific. In other words, in skilled golfers, the calibration should have transferred to the unpracticed side as well. For now, we will leave further evaluation of the skilled golfers dealing with the errors in perceived direction during action through a process of calibration, to Experiment 3.

To sum up, we conducted three experiments to assess how skilled golfers managed the systematic error in perceived direction of the aiming line between the ball and hole when performing a putting action. Experiments 1 and 2 examined the role of head (and eyes) position in the occurrence of the perceptual distortion. This sets the stage for Experiment 3, in which we directly assessed whether the skill-dependent difference between perception and action can be understood as a consequence of education of attention and/or calibration.

Experiment 1

Experiment 1 had two aims. First, we aimed to replicate the previously reported (Johnston et al., 2003) systematic errors in perceived direction in a group of participants that had no experience playing golf. Secondly, we aimed to test the proposition that errors in perceived direction are dependent on the angle between the observer's line of sight, the ground surface, and the true line between the ball and hole. To this end, non-golf-playing participants performed an exocentric pointing task, in which they judged the direction of the aiming line between the ball and hole with their head positioned either directly above or next to the ball when standing to either the left and right of the ball (Figure 2a). We expected clockwise and counter-clockwise errors when the participants stood to the left and right side of the ball respectively, but only in the conditions where their heads were positioned roughly above the hands, in any case next to ball (see Johnston et al., 2003). By contrast, we expected the perceptual errors to reduce to zero when the participants kept their head directly above the ball, as only in this situation would the line of sight be perpendicular to the ground surface (Figure 1). This would allow the exploitation of more useful information that veridically specifies the direction between the ball and hole.

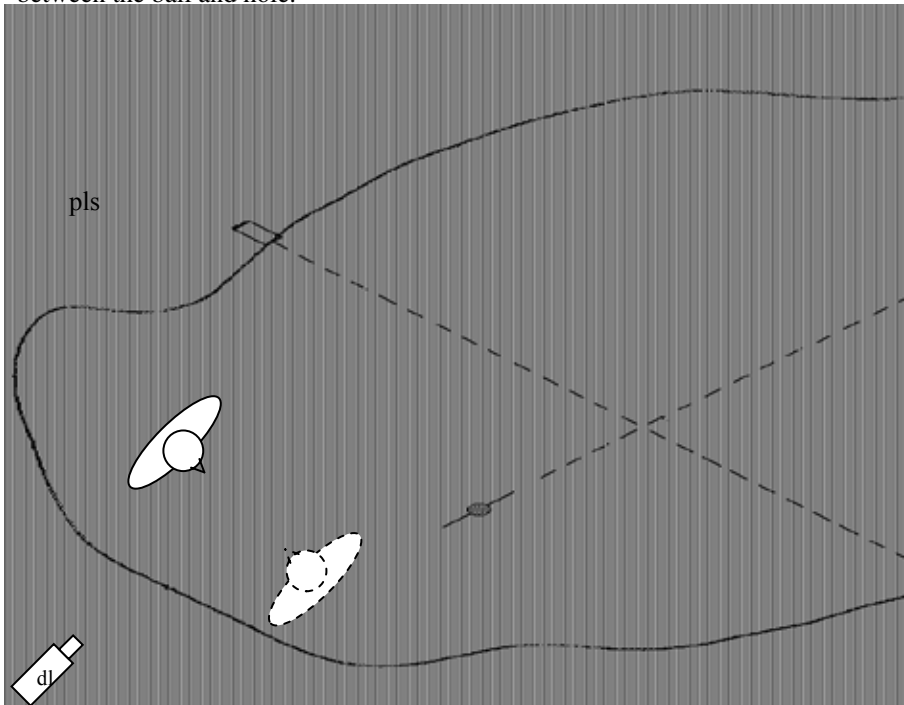


Figure 2 — Top view of the experimental setting. Shown are the green with the hole and the ball (or pointer) at a distance of 2.70 m from the hole. The participant in plain lines stands to the left (i.e., the preferred side of right-handed player), whereas the participant in dashed lines stands to the right. Also shown are the down the line camera (dl) and the photoelectric light switch (pls), as per Experiment 3.

Method

Participants

Twelve⁴ university students (mean age 20.6 ± 2.1 years) with no previous golf experience, two of which were self-described left-handers, participated in this experiment. All participants had normal or corrected to normal vision. The participants were unfamiliar with the aims of the experiment, and provided written consent before the start of the experiment. The experiment was approved by the local ethics committee.

Material and Apparatus

The experiment was carried out in a large laboratory using a triangular shaped level platform, which was covered with synthetic turf and artificial grass (Greenfields, Genemuiden, The Netherlands). The speed of the artificial green was fast (i.e., 14 feet on the Stimpmeter). The pointer that was used comprised of a perforated golf ball through which a 3 mm thick needle protruded 15 cm from the ball's front (i.e., toward the hole) and 10 cm from the ball's back. The pointer was placed 2 cm above the artificial green at a distance of 2.70 m from the hole (13.4 cm in diameter) (Figure 2). The pointer could be rotated in a stepwise fashion by two hand-held switches that fed into a computer. The hand-held switches controlled a servomotor which was connected to the pointer and placed underneath the green. If the pointer was more than 20° off-target at the time the switch was pressed, the rotation speed of the pointer was $6^\circ/\text{s}$. However, the rotation speed was reduced to $1^\circ/\text{s}$ when the pointer was within 20° of the target. The precision of the pointer was $.06^\circ$. The irregularly shaped green was approximately 4 m long and 2 m wide. The edges of the green were covered by black plastic sheeting which hung from the ceiling. The plastic sheeting was wrinkled, creating irregular cavities and protrusions so as to minimize any salient reference points for the participants. In addition, the green was thoroughly cleaned before each participant began putting to prevent the presence of any textures on the green that might be used as a target reference.

Procedure and Design

At the start of each trial, the pointer was automatically placed in a random orientation between 30° and 60° to either the right or left of the hole (this was interchanged from trial to trial). This was done to prevent the participants from making judgments relative to the initial pointer orientation in the current trial and/or the final pointer orientation in the previous trial. Participants were first instructed on how to rotate the pointer by pressing the two hand-held switches. Pressing the switch in the left hand resulted in the pointer rotating in a clockwise direction, while pressing the switch in the right hand made the pointer rotate in an anticlockwise direction. Participants were then instructed to rotate the pointer such that it pointed to the center of the hole. To assist the participants, the center of the hole was indicated by the foot of a flagpole. Once the participants verbally indicated that the pointer was positioned correctly, the computer registered the pointer's exact orientation with respect to perfect aiming line (i.e., the true line between the ball and hole).

The experiment consisted of four conditions. The participants stood either to the left or right side of the ball with their head either directly “above,” or “next to” the ball (i.e., roughly where the hands are would they have putted a ball) (see Figure 1 and 2). The experimenter monitored the head position online via a camera located 3 m behind the ball (in line with the hole). Participants were instructed to stand either nearer or closer to the ball, such that in the “next to” condition their head was positioned approximately 40 cm away from the ball, and in the “above” condition, the head was positioned directly above the ball. Participants were allowed to turn their heads freely in both conditions (i.e., to look from the ball to the hole and vice versa). In the “next to” conditions, the line of sight was approximately at an angle of 75° with the ground surface. The four conditions were administered in blocks of 10 trials (i.e., this number was verified with bootstrap simulations) and counterbalanced across participants. Participants did not receive augmented knowledge of results during the experiment.

Data Reduction and Statistics

The error in perceived direction served as the dependent variable. It was defined as the angle between the direction of the pointer and the direction of the true line between the ball and the hole. A negative angle indicated a counter-clockwise error (i.e., pointing to the left of the hole), whereas a positive angle indicated a clockwise error. The error in perceived direction was submitted to a 2 (side: left, right) \times 2 (head position: next to, above) ANOVA with repeated measures on both factors. A Huynh–Feldt correction to the degrees of freedom was applied in the case of any violations of sphericity and partial eta-squared (η_p^2) values were computed to determine the proportion of total variability attributable to each factor or combination of factors. Post hoc comparisons were made using the Tukey’s HSD test.

Results

The ANOVA revealed a significant effect of side only, $F(1, 11) = 22.29$, $p < .01$, $\eta_p^2 = .67$, indicating that standing to the left resulted in a clockwise error (i.e., positive angles), whereas standing to the right resulted in counter-clockwise error (i.e., negative angles) (see Figure 3). Neither the effect for head position, $F(1, 11) = 2.77$, nor the side by head position interaction, $F(1, 11) = .19$, reached significance. In addition, one sample t tests confirmed that the error in perceived direction differed significantly from zero in each condition, $t_s > 3.38$, $p_s < .01$, except when participants stood to the left with their head above the ball, $t(11) = 2.09$, $p = .06$.

Discussion

Experiment 1 replicated the previous observations by Johnston et al. (2003; see also Koenderink et al., 2000) of systematic errors in perceived direction on an exocentric pointing task. Participants made clockwise errors when they stood to the left of the ball, and counter-clockwise errors when they stood to the right side. In short, the error in perceived direction was an overshoot as would be predicted when the line of sight is *not* perpendicular to ground plane and the true line between the ball and

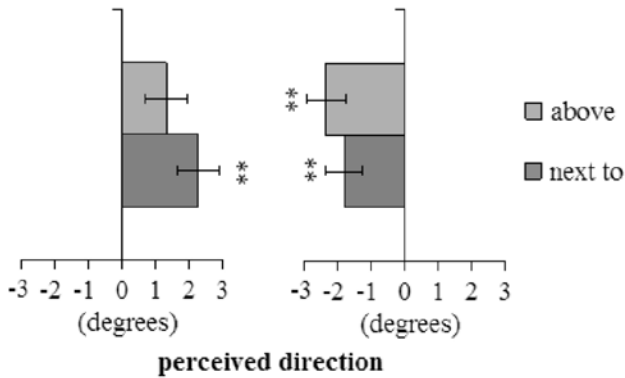


Figure 3 — Errors in perceived direction as a function of head position when participants stood to the right (left panel) or to the left of the ball (right panel) for Experiment 1. Positive and negative errors indicate clockwise and counter-clockwise errors, respectively. * $p < .05$ and ** $p < .01$.

the hole. We also expected that this perceptual error would reduce or even vanish when the line of sight is perpendicular to the green. However, Experiment 1 did not provide unambiguous evidence for the conjecture that perceptual error is reduced when the head is positioned directly above the ball. That is, the error with the head positioned above the ball was not significantly smaller than the perceptual error made with the head positioned next to the ball. Moreover, the error in perceived direction with the head above the ball when standing to the right of the ball was greater than zero. One reason that the perceived error had not vanished may have been that participants could move their head freely, due to which the eyes (i.e., the line of sight) may not have moved in a plane perpendicular to the ground surface. Hence, in Experiment 2 the head movements were constrained in such a way that the eyes could only move in a plane perpendicular to the green through the true line between the ball and hole.

Experiment 2

Experiment 2 aimed to further test the conjecture that the observed errors in perceived direction (i.e., overshoot) reduce or even vanish, when the head and eyes are positioned directly above the ball and constrained to move in the plane perpendicular to the plane in which the directional judgments are made. The same conditions were used as in Experiment 1, but in the “above” condition the participants placed their head in a head mount that only had one axis of rotation (Figure 1, right panel). As per Experiment 1, when participants positioned their head next to the ball, we expected clockwise and counter-clockwise errors in perceived direction when the participants stood to the left and right side of the ball respectively. These errors were expected to be reduced or vanish when the participants positioned the head directly above the ball and were constrained to move the head and eyes in the plane perpendicular to the green.

Method

Participants

Fifteen students with no previous golf experience (mean age 25.5 ± 6.8 years), including three self-described left-handers, participated in this experiment. The volunteers had not participated in Experiment 1, nor were they familiar with the purpose of the experiment. All participants had normal vision or corrected to normal vision and signed an informed consent before the start of the experiment. The experiment was approved by the local ethical committee.

Material and Apparatus

The apparatus and material were the same as in Experiment 1, with the addition of a helmet-like head mount that was used to constrain head position and movements (Figure 1, right panel). On top of the head mount was a rotating metal pin that fixed the head mount to a pole hanging from the ceiling. The head mount could be adjusted to the height of each individual participant. The exact location of the head mount could be adjusted such that the participants were limited to rotate their head from a position directly above the ball, in a plane perpendicular to the ground plane in which they had to judge the direction of the true line between the ball (i.e., the pointer) and the hole. Again, head position and movements were monitored online.

Procedure and Design

As in Experiment 1, there were four conditions with the participants standing either to the left or right of the ball, with their head positioned either “next to” or “above” the ball. Conditions, each consisting of 10 trials, were counterbalanced across participants.

Results

The ANOVA with repeated measures on the error in perceived direction did reveal a significant effect for the side by head position interaction, $F(1, 14) = 6.58, p < .05, \eta_p^2 = .32$. The main effects were not found significant. Tukey post hoc comparisons indicated that with the head next to the ball, the perceived errors for standing to left and to right of the ball were significantly different. By contrast, with the head positioned above the ball, there were no differences in perceived direction as a function of side (Figure 4). One-sample t tests revealed that with the head above the ball, the error in perceived direction did not differ from zero, $ts < .27, ps > .79$. With the head next to the ball the perceived error differed significantly from zero when standing to the right to the ball, $t(14) = 2.44, p < .05$, but not when standing to the left, $t(14) = 1.42, p = .18$.

Discussion

Experiment 2 physically constrained the observers' head to rotate from a position directly above the ball in a plane perpendicular to the ground surface (i.e., green)

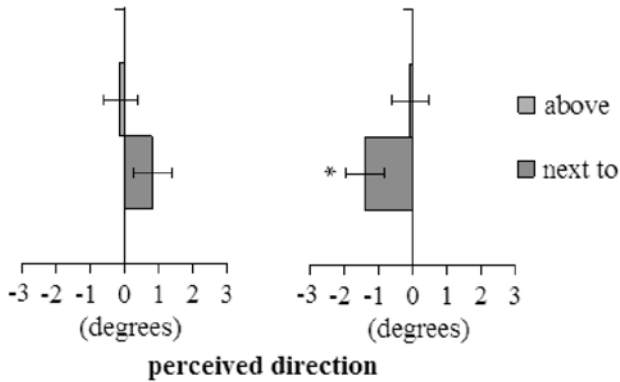


Figure 4 — Errors in perceived direction as a function of head position when participants stood to the right (left panel) or to the left of the ball (right panel) for Experiment 2. Positive and negative errors indicate clockwise and counter-clockwise errors, respectively. * $p < .05$.

through the true line between the ball and the hole. Clearly, this restriction in head position and movement led to errors in perceived direction being destroyed. However, with the head positioned to left or right of the ball (i.e., roughly at the position over the hands would the participants have putted a ball), similar overshoot errors in perceived direction were observed as in Experiment 1 as well as those previously reported by Johnston et al. (2003). We therefore conclude that the errors in perceived direction are a function of head position. This suggests that to access available information that veridically specifies the direction between the ball and hole, a player should prepare for the putting action with the head positioned directly above the ball, and the eyes moving in a plane perpendicular to the green. In contrast, in case the head is not directly above the ball, the golfer can only access less reliable information. Experiment 3 tries to establish whether head position assists golfers in neutralizing the systematic errors in perceived direction while putting.

Experiment 3

Johnston et al. (2003) observed that golfers of differing skill levels made directional errors in the perception of the line between the ball and the hole, and yet these errors did not show up in their putting performance when putting from the preferred side. By contrast, the perceptual errors became apparent in putting when the players putted from their less skillful, nonpreferred side. It seems that the degree to which the perceptual errors manifest themselves in action depends on the level of skill. The purpose of Experiment 3 is to explicate these skill-related differences.

The first hypothesis is that unlike novice players, skilled golfers have learned to position their head directly above the ball in a plane perpendicular to the green. Putting errors reduce to zero, because this head position grants more veridical information about the direction between the hole and the ball. By contrast, novice

players (and, presumably skilled players who putt from their nonpracticed side) may tend to keep their head above the hands (i.e., inside the target line), and hence, fall foul to the perceptual distortion. Hence, it is surmised that systematic directional errors in putting accuracy would in fact be a function of head position rather than skill level. To examine this conjecture, in Experiment 3 we required the novice and high skilled golfers to putt balls toward the hole and perceptually judge the direction of the aiming line between the ball and the hole with the head positioned either directly above the ball or inside the target line (i.e., the head positioned to the left of the ball) (as per Experiment 2). If indeed head position is critical, we expected that irrespective of the participants' skill level, the directional errors would materialize in the putting as well as in the judgment task with the head positioned inside the target line. Yet, these errors were anticipated to reduce or vanish when the tasks are performed with the head directly above the ball.

The second hypothesis refers to the task-dependent pickup and use of information as pointed out by the two-visual systems model (Milner & Goodale, 1995, 2008). According to this model, the errors in perceived direction do not translate into skilled putting, because perception and action do not necessarily rely upon identical sources of optical information. Furthermore, an auxiliary hypothesis holds that unlike for skilled, automatized actions, novice performance entails considerable contribution of conscious perception processes (Gonzalez et al., 2008; Willingham, 1998). Consequently, putting performance of novice players would be much more susceptible to perceptual error than putting performance of high skilled players (see van der Kamp et al., 2008). On basis of these conjectures, we expect that among both the novice and high skilled participants' errors in perceived direction would depend on head position (see above). We further predicted that only putting performance among novices would reflect these perceptual errors. Putting performance of the high skilled participants, by contrast, was expected to be accurate irrespective of head position.

Finally, skilled golfers may have learned to overcome the (purported) initial directional errors in putting through a process of calibration based upon visual feedback from prior putts. That is, golfers learn to reduce the initial directional errors by aiming slightly to the side of the hole opposite to the error, or stated differently, by adjusting the coupling between the putting movements (e.g., orientation of the club) and the optic variable that is specific to the direction between the ball and the hole. It follows that directional putting errors among both the novice and high skilled participants are a function of head position, but with the size of the errors depending on the degree of calibration. Moreover, for the high skilled participants in the perceptual task, an error in perceived direction is expected that is opposite to the direction of calibration (i.e., an initial clockwise or overshoot error in putting would result in a counterclockwise error in perceived direction), whereas for the novice participants the perceptual directional errors should be similar as the putting errors. Notice that under this scenario the degree of calibration is dependent on (initial) head position. Hence, we also determined the preferential unconstrained head position for the novice and high skilled participants from a short preexperimental familiarization session.

Method

Participants

Eleven golf teaching professionals (mean age 34.9 ± 6.9 years; handicaps ranging from 0 to 5) and 11 novice golfers (mean age 27.0 ± 4.4 years, with no previous golf experience) participated. All participants were unfamiliar with the aims of the experiment, were right handed, and had normal or corrected to normal vision. They were treated in accordance with the local institution's ethical guidelines and gave written consent before the start of the experiment.

Material and Apparatus

The experiment was performed on the same platform as in Experiment 2 with the hole at a distance of 2.70 m from the ball. Again, the perceived direction between the ball and the hole was determined with the pointer. For the putting task, a standard peripheral weighted putter and ball were used. Participants wore Plato Liquid Crystal goggles (Translucent Technologies, Toronto, Canada) to remove vision of the ball after it started rolling. The goggles turned opaque after the ball interrupted a light beam of a photoelectric switch (Omron E3S-R 30E4) that crossed the ball path 40 cm from the initial ball position. The removal of vision ensured that participants did not receive visual feedback of the outcome of the putt so they could not optimize the subsequent ones. During the perceptual task, the goggles were closed 250 ms after the participants indicated that they had positioned the pointer correctly.

A digital video recording (25 Hz interlaced PAL) from the top camera was used to determine the initial direction of the ball roll. We used a custom-made motion analysis program HiSpVideo, which is based on the Matlab Image Processing Toolbox, to digitalize ball roll off-line. A second video camera was placed in line with the ball-hole direction to monitor head position of the participants.

Procedure and Design

The experiment started with a familiarization session in which participants performed 10 consecutive putts without any constraints on the head position. Participants wore goggles to eliminate visual feedback. The putts from this familiarization session were used to determine the participants' preferential head position. Next, the participants performed the perceptual judgment and putting tasks standing on the left side of the ball with the head either "next to" (i.e., inside the target line, approximately above the hands) or directly "above" the ball. In the latter condition, the participants positioned the head in the helmet-like head mount that was fixed to a pole, such that they were constrained to rotate their head from a position directly above the ball in a plane perpendicular to the ground plane (as per Experiment 2). In both tasks, they were instructed to perform as accurately as possible without any time constraints. Participants performed 10 repetitions for each blocked task and condition, the order of which was counterbalanced across participants.

Data Reduction and Statistics

Preferential head position was categorized by means of video recordings from the camera placed behind the ball. The head position at the onset of the back swing was determined by measuring the distance between the edge of the eye and the vertical perpendicular to the ball in cm. A distance within 5 cm off the perpendicular line through the ball was categorized as the head being positioned above the ball. A one-way ANOVA was used to compare preferential head position between groups. An ANOVA with repeated measures was conducted to compare the number of putting errors to the right and left of the hole between the groups during the familiarization session.

The error in perceived direction (in degrees) was defined as the angle between the direction of the pointer and the direction of the perfect target line between the ball and the hole. For the error in putting direction, a custom-made semiautomatic video-analyzing program was used to determine the angle between the initial direction of ball roll and the true line between the ball and hole from the top camera with the overhead view. The angle was defined as the average angle for the first 10 frames (i.e., 400 ms) after the ball started moving. Negative angles for the errors in perceived and putting direction indicated a counter-clock wise error (i.e., undershoot), while positive angles indicated a clockwise error (i.e., overshoot). The errors were submitted to a 2 (skill level: novices, high skilled) by 2 (task: perceptual judgment, putting) by 2 (head position: next to, above) ANOVA with repeated measures on the last two factors. A Huynh-Feldt correction to the degrees of freedom was applied in the case of any violations of sphericity and partial eta-squared (η_p^2) values were computed to determine the proportion of total variability attributable to each factor or combination of factors. Post hoc comparisons were made using Tukey's HSD test.

Results

Preferential head position during the unconstrained familiarization trials showed that the high skilled golfers kept their head predominantly straight above the ball, while the novice participants did so only in the minority of trials (i.e., $M = 88.8\%$, $SD = 31.8$ and $M = 25.6\%$, $SD = 41.6$ for the high skilled and novice participants respectively). A one-way ANOVA indicated that this difference was significantly different, $F(1, 16) = 12.13$, $p < .01$, $\eta_p^2 = .45$. In addition, during the initial 10 familiarization trials, the high skilled participants made an equal amount of putting errors to the right ($M = 2.9$, $SD = 3.0$) and to the left of the hole ($M = 2.3$, $SD = 3.1$), whereas for the novices the frequency of errors to the right ($M = 5.2$, $SD = 2.4$) was numerically higher than the frequency of errors to the left ($M = 2.0$, $SD = 2.2$). Yet, the repeated-measures ANOVA did not confirm that these differences were statistical reliable.⁶ Both the main effect of group, $F(1, 15) = 3.97$, $p = .06$, $\eta_p^2 = .21$, as well as the interaction between group and type of error, $F(1, 15) = 1.18$, $p > .10$, $\eta_p^2 = .15$.

Figure 5 shows the alignment errors for the novice and high skilled golfers as a function of task and head position. The pattern of errors in perceived direction for the novices compared well to the perceptual errors found in Experiments 1 and 2 when participants stood at the left hand side (see the left bars in Figures

3–5). With the head next to the ball, they were inclined to make rightward errors, albeit that in the present experiment the two-tailed t test did not confirm that the error differed significantly from zero, $t(10) = 1.81$, $p = .10$. The directional error is clearly destroyed with the head positioned straight above the ball, $t(10) = .29$, $p = .77$. Nonetheless, Figure 5 suggests that the alignment errors are not only affected by head position, but also by task and skill level. That is, the analysis of variance not only revealed a significant effect for head position, $F(1, 20) = 4.80$, $p < .05$, $\eta_p^2 = .19$, but also significant effects for task, $F(1, 20) = 14.81$, $p < .01$, $\eta_p^2 = .43$, and task by head position, $F(1, 20) = 5.48$, $p < .05$, $\eta_p^2 = .22$. Post hoc analysis indicated that with the head positioned straight above the ball a leftward (i.e., clockwise) shift occurred in the alignment relative to when the head is positioned next to the ball (i.e., above the hands). For the high skilled participants this shift even resulted in a significant leftward bias in the perception task with the head straight above the ball, $t(10) = 2.72$, $p < .05$. This shift as a function of head position, however, only occurred in the perception task and not in the action task, resulting in aligning more to the right for the action task compared with the perception task. These effects were not mediated by skill level, yet the analysis of variance did show a significant main effect of skill level, $F(1, 20) = 7.06$, $p < .05$, $\eta_p^2 = .26$, indicating that the novices golfers aimed more to the right than the high skilled golfers in both tasks. Consequently, whereas the alignment bias during putting among the high skilled participants did not significantly differ from zero, the novice participants putted the balls significantly to the right of the hole for both head positions, $t(10)$'s > 3.1 , $ps < .05$.

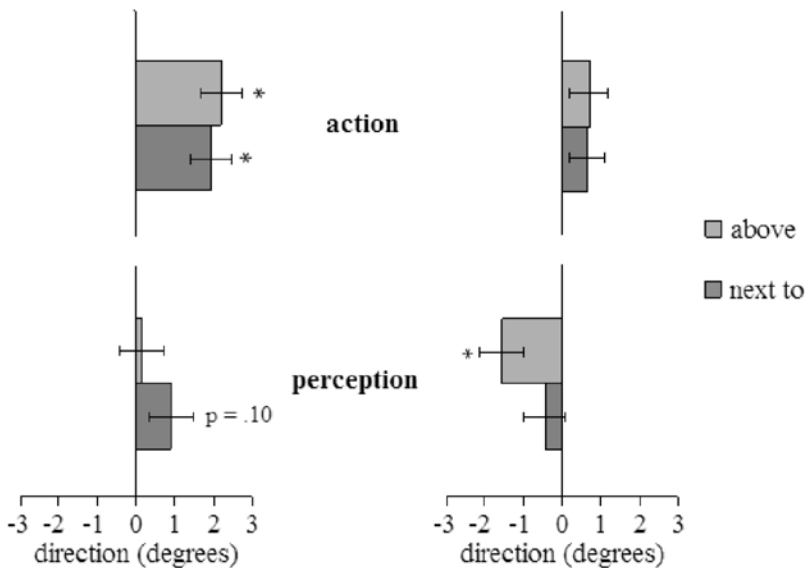


Figure 5 — Alignment error as a function of task and head position for novice (left panel) and high skilled participants (right panel) for Experiment 3. Positive and negative errors indicate clockwise and counter-clockwise errors, respectively. * $p < .05$.

Discussion

There are two important findings of Experiment 3 that come to the fore. First, the discrepancy in the patterns of errors that were revealed in the perception of direction and in putting accuracy, and second, the disparity in the patterns of error among the novice and high skilled participants. We start with the former.

The two-visual systems model (Milner & Goodale, 1995; 2008) proposes that the pickup and use of visual information is task dependent. More precisely, vision to control movement execution (i.e., action) operates relatively independent of vision to obtain knowledge of the environment (i.e., perception). The discrepancies in directional errors observed in the present experiment are consistent with this task-dependency. Thus, relative to perceived direction, during putting the balls were consistently aimed more rightward during actual putting. More importantly, the position of the head did not affect alignment in putting, whereas it had a clear impact on perceived direction (as per Experiment 1 and 2). We make two inferences. First, the high skilled participants' greater putting accuracy is not merely due to the high skilled participants maintaining their head (and eyes) directly above the ball, whereas novices hold their head inside the true line. On the contrary, the skill-related differences in putting accuracy were independent of head position. Consequently, we do not find evidence to support the contention that high skilled players have annulled the (initial) errors in putting by positioning head and eyes directly above the ball, thereby enabling them to exploit better specifying information for the true line between ball and hole. The apparent disparity in *preferred* head position between the novice and high skilled players has most likely arisen for reasons other than aligning the orientation of the club head to the ball. Second, the task-dependent findings point to the pickup and use of different information for the perception of the direction of the hole and the control of the orientation of the club head relative to the ball in putting. As matter of fact, this difference occurred irrespective of skill level. This questions the hypothesis that with increase in putting skill the extent to which conscious perceptual processes contribute to action decreases (cf. Gonzalez et al., 2008; van der Kamp et al., 2008). In sum, we did not find evidence that the observed skill-related difference in putting accuracy is associated with a change in the allocation of attention to better specifying information.

In both the perception and the putting task, the high skilled golfers aimed more to the left than the novices. Novices, on average,⁷ putted the ball to the right of the hole, reflecting an alignment error that is in line with the error in perceived direction, albeit somewhat exaggerated. By contrast, the high skilled were more accurate in putting direction. Relative to the novices, they had learned to aim the ball more to the left, thus achieving much more accurate putts. Notably, a comparison of the errors in perceived direction between the high skilled and novice participants revealed a similar directional difference as in putting. This skill-related leftward difference supports the hypothesis that with practice, the high skilled players have canceled out the initial rightward errors in putting through a process of calibration based upon visual feedback from prior putts. Perceiving that the ball tends to miss the hole to the right may result in the novice players aiming the next putt slightly more to the left, therewith scaling the relation between the optic variable that specifies the direction of the putting movement. Intriguingly, the concomitant leftward shift in perceived direction suggests that this calibration is not restricted to action,

but may generalize to perception as well. The broader significance of this transfer will be discussed in the next section.

In sum, consistent with Johnston et al. (2003), we found that errors in perceived direction of the hole did not simply translate into putting, particularly among the high skilled participants. For the novices, similar rightward errors were found in perception and putting, although of a different magnitude. It seems that high skilled players become refractory to the initial alignment errors through a process of calibration, rather than using different optical sources of information.

General Discussion

Visual perception does not always result in veridical awareness of the environment. Perceivers occasionally do not exploit optic variables that accurately specify objects, events and places either because the specifying information is not available or because the perceiver is not attuned to it. The present study addressed how nonveridical perception affects sport performance in general, and golf putting in particular. In agreement with previous reports by Koenderink and colleagues (Cuijpers et al., 2000, 2003; Koenderink & van Doorn, 1998; Koenderink et al., 2000, 2003; see also Johnston et al., 2003), the current study shows that one property for which observers may make systematic perceptual errors is the direction of a line. Although, the nature of this error in perceived direction is not well understood, one suggestion is that it depends on the ratio of the distances of the two end points of the (virtual) line (i.e., the true line between ball and hole) to the observer (Koenderink & van Doorn, 1998; Koenderink et al., 2003). Hence, more precise information concerning these distances should reduce errors in perceived direction. Accordingly, we demonstrated that with the head positioned directly above the ball the perceptual error is nullified. We argued that the angle between the line of sight, the ground plane and the true line between the ball and the hole is critical for the directional error to disappear, but also note that alternative explanations (e.g., the absolute or lateral distance between the observer and the ball) cannot be ruled out based on the current study alone.

Whatever the exact cause, the nonveridical perception of direction poses difficulties for accurate guidance of a putting action, and raises the issue of how skilled golfers overcome the perceptual distortions. At heart of this issue is the relationship between perception and action. In this respect, Rossetti (1998) distinguishes two general theoretical views (see Figure 6). The serial view, which seamlessly fits in the traditional Cartesian view, holds that perception enslaves action. That is, action is based upon and controlled by perception without necessity of any further transformation. The implication is that any perceptual error due to suboptimal information-perception relations will be reflected in action. By contrast, the parallel view of perception and action posits that perception and action are separate and largely independent functions that exploit different information (e.g., Milner & Goodale, 1995; 2008; see also Michaels, 2000; van der Kamp et al., 2003, 2008). Significantly, from this parallel view, distortions in perception do not need to become apparent in action.

The current study does not provide unequivocal support for either view. On the one hand, the finding that manipulating head position affects the pattern of directional errors differently in perception and action points to perception and action

operating independently. The use of information for the perception of direction and the use of information to control the direction of the swing in putting seem distinct, relatively modularized processes. In fact, the rescaling or calibration of the relationship between information and movement variables (e.g., the orientation of the club head relative to the ball) with increments in skill is also entirely consistent with an autonomous functioning of action. Yet, relative to the novices, the high skilled participants did not only putt more to the left, they also perceived the direction of the hole more to the left. Hence, calibration was not restricted to action, but also comprises the relationship between information and perception. This interaction between perception and action is easier to reconcile with a serial view than with a parallel view of perception and action. From a serial view, the following scenario could be envisioned. Directional errors in putting provide feedback or information to adaptively scale the relationship between information and perception. As a consequence, errors in perceived direction will gradually reduce, which in turn leads to ever-slighter errors in putting. In other words, the serial view anticipates that changes in perception and action would go hand in hand. Nonetheless, it seems to us that at present any verdict on the aptness of the two views is somewhat premature. One possible next step would be to further substantiate our conclusion that observed skill-related differences in putting skill may reflect a process of calibration. To this end, we need to go beyond comparing *differences* in performance of novice and high skilled players, and directly investigate the *changes* that occur in both perception and action in the learning process of the putting skill.

How should golfers preparing to hole a ball, or sports players in other precision-based aiming tasks, deal with the observed nonveridical perception of direction? Before actually executing a putt, it is important for the player to read the green before addressing the ball (i.e., preparing the actual swing). By reading the green, the golfer can gather information over and beyond information used to control the direction of the swing, such as information about the pace and slope of the green (e.g., van Lier et al., 2010). This will aid to (consciously) set the boundary constraints within which the movement system autonomously picks up and uses information for the execution of the swing. A conventional technique to overcome errors in perceived direction is the logo alignment aid (Farnsworth, 1997). With this technique, the player must stand behind the ball before addressing it. From this point of view, the player can accurately position the ball so that its logo or any other elongated mark on the ball is aligned with the true line between the ball and hole. Finally, while addressing the ball to execute the swing, the player aligns the putter to the logo instead of the hole. To accomplish this, gaze should only be directed to the ball and not to the hole. This way, the player does not fall fool to distortions in perceived direction, and additionally, may benefit from a prolonged final fixation before executing the putting movement (Vickers, 1996). To the extent that biases in putting direction are caused by biases in perceived direction, the logo alignment aid and intermediate aiming strategy seem appropriate. In this regard, the present results suggest that novices would benefit more from this technique than high skilled players. However, we also observed that the errors in the perception of the direction in which the ball must roll to be holed, particularly among the high skilled, does not directly translate into the putting action. Particularly, it was found that although a change in head position annulled errors in perceived direction, it did not affect biases in putting accuracy. Thus, we found no unambiguous evidence that the use

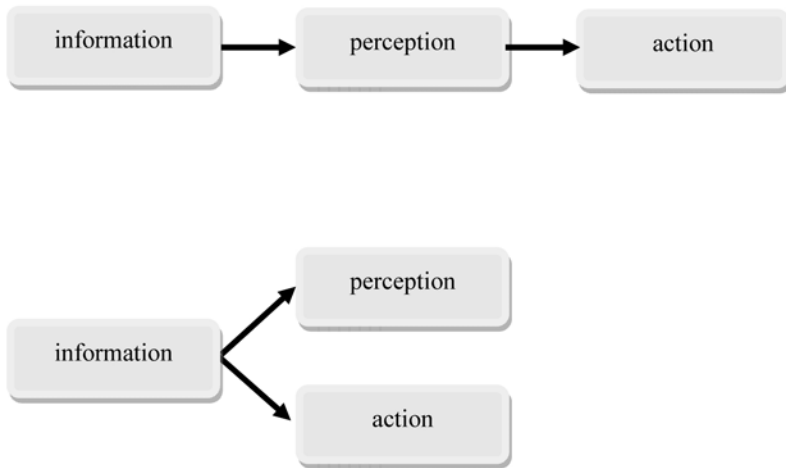


Figure 6 — Schematic representation of the serial view (top) and parallel view (bottom) of perception and action.

of information to control the swing can be augmented or improved by the golfer maintaining the head directly above the ball, at least as far as it concerns the present errors in perceived direction. Instead, it may be more important for the player to obtain knowledge about the type of putting errors, because this may be used to make adaptive adjustments in aiming. Whether perceptual learning alone will be sufficient to realize these adjustments in aiming is, as yet, not completely clear.

Notes

1. These are both dubbed overshoot errors because the pointer must be turned back toward the observer to accurately point at the target.
2. We restrict ourselves to vision, yet it should be clear that this relation may include proprioceptive, haptic or tactile, and auditory information as well.
3. Actually, golfers are urged to keep their eyes straight above the ball for a slightly different reason. Pelz (2000), for instance, argues that golfers have the tendency to modify their aim based on their alignment angle, that is, the angle between the eyes and the hole, and the ball and the hole. As this alignment angle is a function of distance, Pelz advises to keep the eyes vertically above the aim line because only in this way does it not vary as a function of distance.
4. The number of participants was determined with bootstrap simulations on the perceived direction. Bootstrap simulations indicate that adding more participants would not result in a 5% or more reduction of between participant variance (see Hoozemans, Burdorf, van der Beek, Frings-Dresen, & Mathiassen, 2001).
5. Due to equipment failure, the head position of one high skilled participant could not be determined.
6. The number of participants was mainly derived from the bootstrap analyses performed in Experiments 1 and 2. Hence, we cannot exclude the possibility that Experiment 3 is somewhat underpowered and that statistically different patterns may emerge in studies with greater power.

7. As control of the stroke is poor among novice golfers, one might argue that putt direction may not accurately reflect aiming. However, presuming that poor control results in stochastic errors in direction, the average of series of putts will reflect direction of aiming.

References

- Bedford, F.L. (1999). Keeping perception accurate. *Trends in Cognitive Sciences*, 3, 4–11.
- Bruno, N., Bernardis, P., & Gentilucci, M. (2008). Visually guided pointing, the Müller-Lyer illusion, and the functional interpretation of the dorsal-ventral split: Conclusions from 33 independent studies. *Neuroscience and Biobehavioral Reviews*, 32, 423–437.
- Catteeuw, P., Helsen, W., Gilis, B., Van Roie, E., & Wagemans, J. (2009). Visual scan patterns and decision-making skills of expert assistant referees in offside situations. *Journal of Sport & Exercise Psychology*, 31, 786–797.
- Cuijpers, R.H., Kappers, A.M., & Koenderink, J.J. (2000). Investigation of visual space using an exocentric pointing task. *Perception & Psychophysics*, 62, 1556–1571.
- Cuijpers, R.H., Kappers, A.M., & Koenderink, J.J. (2003). The metrics of visual and haptic space based on parallelity judgments. *Journal of Mathematical Psychology*, 47, 278–291.
- Farnsworth, C.L. (1997). *See it and sink it: Mastering putting through peak visual performance*. New York: Harper & Row.
- Gibson, J.J. (1986). *The ecological approach to visual perception*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Gonzalez, C.L.R., Ganel, T., Whitwell, R.L., Morrissey, B., & Goodale, M.A. (2008). Practice makes perfect, but only with the right hand: Sensitivity to perceptual illusions with awkward grasps decreases with practice in the right but not the left hand. *Neuropsychologia*, 46, 624–631.
- Hoozemans, M.J., Burdorf, A., van der Beek, A.J., Frings-Dresen, M.H., & Mathiassen, S.E. (2001). Group-based measurement strategies in exposure assessment explored by bootstrapping. *Scandinavian Journal of Work, Environment & Health*, 27, 125–132.
- Jacobs, D.M., & Michaels, C.F. (2007). Direct learning. *Ecological Psychology*, 19, 321–349.
- Johnston, A., Benton, C.P., & Nishida, S. (2003). Golfers may have to overcome a persistent visuospacial illusion. *Perception*, 32, 1151–1154.
- Karlsen, J., Smith, G., & Nilsson, J. (2008). The stroke has only a minor influence on direction consistency in golf putting among elite players. *Journal of Sports Sciences*, 26, 243–250.
- Koenderink, J.J., & van Doorn, A.J. (1998). Exocentric pointing. In L.R. Harris & M. Jenkin (Eds.), *Vision and action* (pp. 295–313). Cambridge, UK: Cambridge University Press.
- Koenderink, J.J., van Doorn, A.J., & Lappin, J.S. (2000). Direct measurement of curvature of visual space. *Perception*, 29, 69–79.
- Koenderink, J.J., van Doorn, A.J., & Lappin, J.S. (2003). Exocentric pointing to opposite targets. *Acta Psychologica*, 112, 71–87.
- Mangum, G. (2008). *Optimal putting: Brain science, instincts, and the four skills of putting*. Cumming, GA: Axxess Book Printing.
- Mann, D.T., Williams, A.M., Ward, P., & Janelle, C.M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport & Exercise Psychology*, 29, 457–478.
- Michaels, C.F. (2000). Information, perception, and action: What should ecological psychologists learn from Milner and Goodale (1995)? *Ecological Psychology*, 12, 241–258.
- Milner, A.D., & Goodale, M.A. (1995). *The visual brain in action*. Oxford: Oxford University Press.
- Milner, A.D., & Goodale, M.A. (2008). Two visual systems re-viewed. *Neuropsychologia*, 46, 774–785.
- Oudejans, R.D.D., Verheijen, R., Bakker, F.C., Gerrits, J.C., Steinbrückner, M., & Beek, P.J. (2000). Errors in judging “offside” in football. *Nature*, 404, 33.

- Panchuk, D., & Vickers, J.N. (2006). Gaze behaviors of goaltenders under spatial-temporal constraints. *Human Movement Science*, 25, 733–752.
- Pelz, D.T. (2000). *Dave Pelz's putting bible: The complete guide to mastering the green*. London: Aurum Press.
- Rieser, J.J., Pick, H.L., Jr., Ashmead, D.H., & Garing, A.E. (1995). Calibration of human locomotion and models of perceptual-motor organization. *Journal of Experimental Psychology. Human Perception and Performance*, 21, 480–497.
- Rossetti, Y. (1998). Implicit short-lived motor representations of space in brain damaged and healthy subjects. *Consciousness and Cognition*, 7, 520–558.
- Savelsbergh, G.J.P., & van der Kamp, J. (2000). Information in learning to co-ordinate and control movements: Is there a need for specificity of practice? *International Journal of Sport Psychology*, 31, 467–485.
- Van der Kamp, J., Oudejans, R.D.D., & Savelsbergh, G.J.P. (2003). The development and learning of the visual control of movement: An ecological perspective. *Infant Behavior and Development*, 26, 495–515.
- Van der Kamp, J., & Masters, R.S.W. (2008). The human Müller-Lyer illusion in goalkeeping. *Perception*, 37, 951–954.
- Van der Kamp, J., Rivas, F., van Doorn, H., & Savelsbergh, G.J.P. (2008). Ventral and dorsal system contributions to visual anticipation in fast-ball sports. *International Journal of Sport Psychology*, 39, 100–130.
- Van Lier, W., van der Kamp, J., & Savelsbergh, G.J.P. (2010). Gaze in golf putting: Effects of slope. *International Journal of Sport Psychology*, 41, 160–176.
- Vickers, J.N. (1992). Gaze control in putting. *Perception*, 21, 117–132.
- Vickers, J.N. (1993). Toward defining the role of gaze control in complex targeting skills. In D. Brogan, A. Gale, & K. Carr (Eds.), *Visual search*, 2 (pp. 265–286). Bristol: Taylor & Francis.
- Vickers, J.N. (1996). Visual control when aiming at a far target. *Journal of Experimental Psychology. Human Perception and Performance*, 22, 342–354.
- Warren, W.H. (1988). The perception-action coupling. In H. Bloch & B.I. Bertenthal (Eds.), *Sensory-motor organizations and development in infancy and early childhood* (pp. 23–37). Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Willingham, D.B. (1998). A neuropsychological theory of motor skill learning. *Psychological Review*, 105, 558–584.
- Wilson, M.R., Wood, G., & Vine, S.J. (2009). Anxiety, attentional control, and performance impairment in penalty kicks. *Journal of Sport & Exercise Psychology*, 31, 761–775.
- Wilson, M.R., Vine, S.J., & Wood, G. (2009). The influence of anxiety on visual attentional control in basketball free throw shooting. *Journal of Sport & Exercise Psychology*, 31, 152–168.
- Withagen, R., & Michaels, C.F. (2005). The role of feedback information for calibration and attunement in perceiving length by dynamic touch. *Journal of Experimental Psychology. Human Perception and Performance*, 31, 1379–1390.

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